Final Report

Award Number: 02HQGR0156

Project Title:
LABORATORY STUDY OF THE EFFECTS OF DYNAMIC STRESSES ON FAULT STRENGTH

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Summary

Recent studies show that earthquake-induced stress changes can trigger fault slip, changes in seismicity rate, and additional damaging earthquakes. Previous studies of stress triggering have focused primarily on static stresses using the Coulomb failure model. However, dynamic stresses are also expected to be important in earthquake triggering, particularly at large distances from the mainshock. Recent theoretical work shows that dynamic stressing can lead to destabilization of creeping faults and resonant behavior, characterized by large amplitude stick-slip instabilities. Numerical models are available to study dynamic stressing and their role in earthquake triggering and fault interaction. However, there has been a paucity of laboratory data in this area and the data necessary to carry out theoretical studies are few. Laboratory data are needed to account for changes in fault strength and to understand the effects of dynamic stresses on frictional properties and stability. These data are important for NEHRP research objectives and can help reduce earthquake related losses in the US by improving models for fault interaction and short-term changes in seismic hazard associated with earthquakes.

This proposal was to carry out detailed laboratory studies of the effects of normal load fluctuations on frictional strength and stability, including resonant behavior and shear destabilization. We imposed two types of dynamic stresses during steady creep and stick-slip. Our results have been used to test theoretical models based on friction constitutive laws. Normal load oscillations, loading rate oscillations, and normal load step tests were used to determine the material constitutive response for simulated fault gouge. Results of the proposed experiments are expected to have significant impact on understanding fault mechanics and earthquake physics including triggering of seismic and aseismic fault slip, fault interaction, and seismic hazard assessment.

Normal Stress Stepping Experiments:

A total of 58 experiments have been performed. Details are given for a subset of the experiments in Table 1. We sheared layers of granular quartz powder between roughen blocks at sliding velocities from 3 to 1000 micron/sec. Nominal frictional contact dimensions were 10 x 10cm. In each experiment, we sheared layers through a standard displacement history to establish a steady-state friction level and then imposed step changes in normal stress during steady sliding.

The parameter alpha was obtained for experiments at each individual sliding velocity (Figure 1)

Modeling:

We modeled data using both the Dieterich and Ruina rate and state friction laws (see box). Friction parameters were obtained by fitting velocity step tests and Poisson elastic effects of the apparatus were accounted for.

$$\tau = \mu_0\sigma + A\sigma \ln(V/V_0) + B\sigma \ln(\theta/\theta_0)$$

$$\frac{d\theta}{dt} = -\frac{V\theta}{D_C}\ln\left(\frac{V\theta}{D_C}\right) - \left(\frac{\alpha\theta}{B\sigma}\right)\frac{d\sigma}{dt} \quad \text{State evolution}$$

$$\frac{\Delta\tau}{\sigma} = \alpha \ln\left(\frac{\sigma}{\sigma_0}\right) \quad \text{for normal stress step}$$

$$\frac{d\tau}{dt} = K(V_0 - V), \quad \text{K is the system stiffness}$$

$$S\Delta\sigma \Rightarrow \Delta\tau \quad \text{, Poisson effect using factor S}$$

Results of normal stress step tests at sliding velocities of 3 and 600 micron/sec. are shown in Figures 2 and 3 respectively. While the models fit the general character of the data, two problems are noted. 1) In experimental data, the Coulomb friction coefficient at the start of a step is different from that at the end of the step. This leads to the difference between the steady state stress level of the data and model (Figure 2). 2) At present, we find appreciable differences between data and model results for high velocity (Figure 3). This is especially true during initial evolution following a normal stress step.

Publications Resulting From Work To Date

Boettcher, M. S., and Marone, C., The effect of dynamic normal stress variation on the strength and stability of creeping faults, Submitted to *J. Geophys. Res.*,

Anthony, J., Marone, C., The effect of particle size, dimension, and roughness on friction and stick-slip instability in granular fault gouge, *SCEC Ann. Mtg.* 2003.

Savage, J., Marone, C., The effect of load rate oscillations on shear strength and stability in laboratory faults, *SCEC Ann. Mtg.* 2003.

Anthony, J., Marone, C., The effect of humidity and particle characteristics on friction and stick-slip instability in granular fault gouge, *Eos, Trans., Am. Geophys. Un.*, F 2003.

Hong, T. Marone, C., Effects of Variable normal stress on shear strength and friction, *Eos, Trans., Am. Geophys. Un.*, F 2003.

Anthony, J., Marone, C., The effect of particle characteristics on stick-slip instability in granular fault gouge, SM12-1MO1P-0201, *Eos, Trans., Am. Geophys. Un.*, S 2003.

Savage, H., Marone, C., The effect of dynamic stress on shear strength and stability in laboratory faults, *Eos, Trans., Am. Geophys. Un.*, F 2003.

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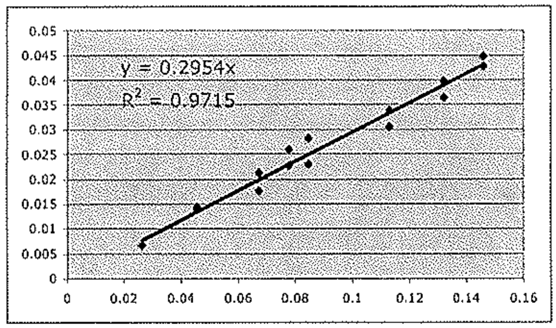

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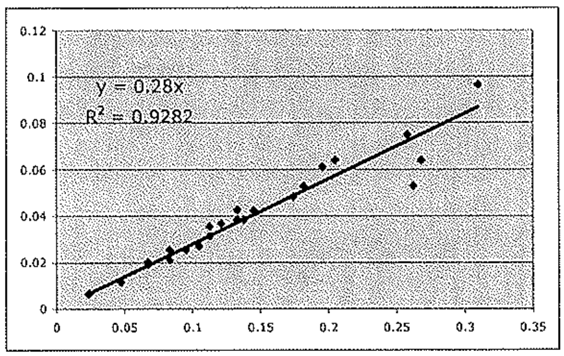

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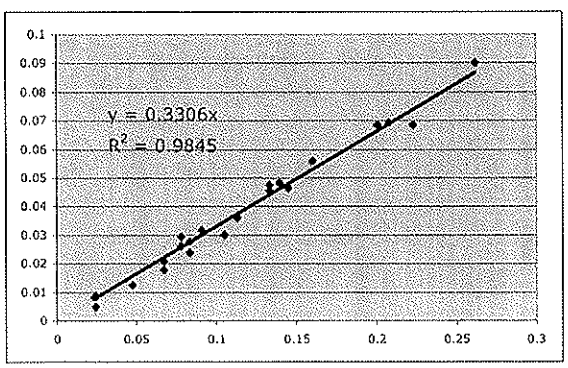

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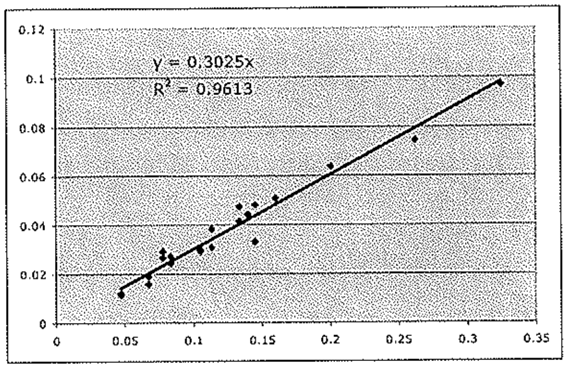

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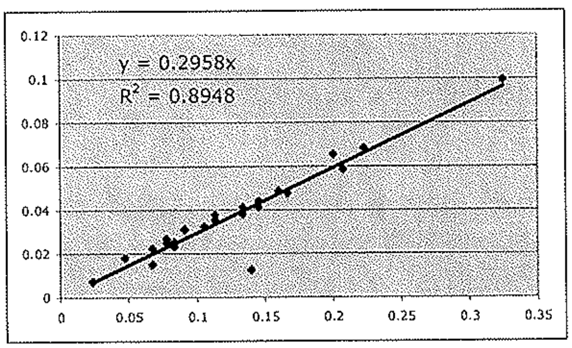

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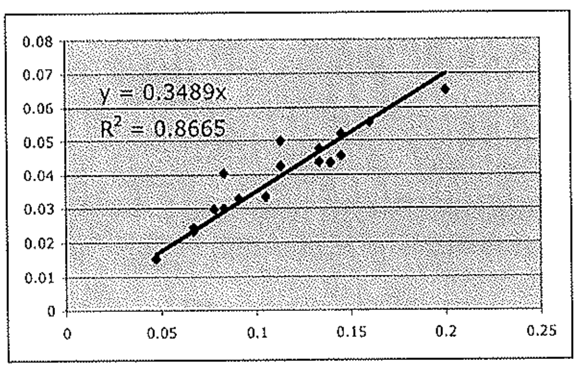

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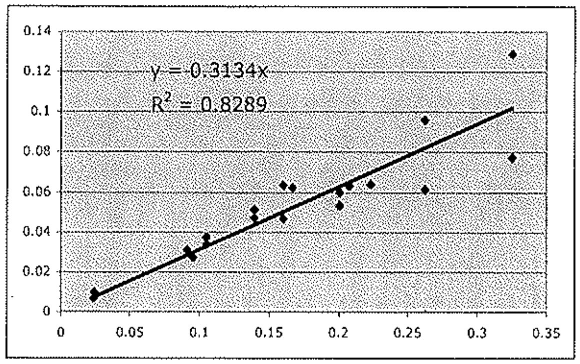

Figure 3. Parameter alpha from normal stress stepping experiments